SB 551

LEAGUE OF WISCONSIN MUNICIPALITIES

202 State Street
Suite 300
Madison, Wisconsin 53703-2215

608/267-2380
800/991-5502
Fax: 608/267-0645

E-mail: league@lwm-info.org
www.lwm-info.org

To: Members of the Senate Environment and Natural Resources Committee

From: Curt Witynski, Assistant Director, League of Wisconsin Municipalities

Date: February 19, 2004

Re: **Support for LRB 3797/4, Providing Municipalities with Flexibility in Complying with the Federal Radium Standard**

The League of Wisconsin Municipalities supports LRB 3797/4, which would allow communities to keep wells exceeding the federal radium standard of 5 picocuries per liter connected to the municipal water distribution system, as long as the wells meet all other safety standards. Consistent with federal law, communities would be allowed to use water from these wells as long as the radium level of the water tested between the well and the first customer is below the standard of 5 picocuries per liter. This would be accomplished through blending or treatment within the distribution system.

The League supports this bill because it will provide the over 30 municipalities affected by the radium issue with the flexibility they need to more affordably comply with the federal radium standard. Communities across Wisconsin have been ordered to comply with a federal mandate to reduce radium levels in the public water supply by 2006. The Wisconsin Department of Natural Resources (DNR) currently requires that all wells connected to a public water system be in compliance with the federal standard of 5 picocuries of radium per liter at the entry point to the distribution system. The DNR requires communities to abandon noncomplying wells or to engage in expensive treatment of these wells even if they would be used only in emergencies or during high use periods. Federal law does not require this. The Environmental Protection Agency allows sampling of a well connected to a water distribution system between the well and the first customer.

This bill will allow communities with wells that exceed the federal radium standard to keep the wells connected to the water distribution system for use in emergencies or during high use periods. This bill will enable communities to meet the federal radium requirement in a cost-effective way while ensuring that public health will continue to be protected.

For these reasons, we urge you to recommend passage of LRB 3797/4. Thanks for considering our comments on this important piece of legislation.

Testimony of the Department of Natural Resources
Relating to Draft Legislation LRB 3797/4, February, 19, 2004
Committee on Environment and Natural Resources

Thank you for the opportunity to provide comments on statutory changes proposed in LRB 3797/4. My name is Jill Jonas and I am the Director of the Bureau of Drinking and Groundwater in the Department of Natural Resources.

I am appearing this morning in opposition to the statutory changes proposed in this legislation. The Departments understanding of the objectives of this proposed change are; (a) to allow public water systems to keep radium contaminated wells connected to their distribution systems indefinitely and, (b) allow public water systems to move the point at which safe drinking water standards are applied such that, "average" radium concentrations in the distribution system would comply with the MCL for radium.

This legislation would allow any radium contaminated well to be connected to a municipal system without treatment. It would allow water systems to knowingly distribute water from sources with radium concentrations above safe drinking water standards. Certain consumers within the water system would preferentially receive high doses of radium contaminated drinking water.

Although the proposed legislation is specifically written for radium, the Department believes we could not successfully defend exclusion of all other chronic contaminants from similar allowances.

Systems could retain these contaminated wells indefinitely, which poses a direct threat to major drinking water aquifers in the State by allowing an open conduit for contamination. We believe these contaminated, unused wells should be abandoned.

This legislation allows mixing of contaminated and uncontaminated water within the water distribution system. Documenting compliance with drinking water standards inside the system under a mixing scenario will be exceedingly complex and expensive. The Department would need to review every alternative compliance plan, establish system specific plans, modify and maintain a database to track compliance at an extraordinary level of detail. Resources will be needed to address the significant increase in data and increased oversight.

The Department has conferred extensively with the Wisconsin Department of Health and Family Services, Division of Health and they concur that the proposed legislation would be less protective of public health than the Department's current policy. A lead toxicologist for Health and Family Services stated in part: " . . .*even brief, intermittent exposures have the potential to increase an individual's lifetime cancer risk. This risk will be highest in those who are young at the time of exposure, and those who are unable to repair genetic damage* . . .". The riskiest period for exposure is from birth to age 18.

Finally, the Department has reviewed this issue with other State safe drinking water agencies nationwide and to date, we have not found a single State that allows mixing contaminants in the water distribution system as a means of compliance. We have found several States that would allow blending of sources *prior* to entry to the water distribution system, to meet compliance. Wisconsin currently allows such blending prior to the entry point.

Mary Lazich

Wisconsin State Senator
Senate District 28

Senate Committee on Environment and Natural Resources
Testimony for LRB 3797/4
February 19, 2004

Thank you, Chairman Kedzie, for holding a hearing today on LRB 3797/4. I urge the Committee to support this legislation to allow communities with wells that exceed the radium standard to keep the wells connected to the public water system, in accordance with federal law. The wells will be required to meet all other standards set by the Wisconsin Department of Natural Resources (DNR). Current DNR rules prohibit wells that produce water with elevated radium levels from being connected to a public water system unless blending or treatments is provided before entry of the water to the distribution system. The DNR allows communities to use water from wells that exceed the radium standard only in very limited circumstances and requires that these wells be abandoned after five years.

As you may know, more than 50 communities in Wisconsin are under state orders to reduce radium levels in drinking water by December 2006. Most of the communities are in eastern Wisconsin, falling largely within a band that curves from De Pere through Fond du Lac to Racine County. These communities pump water from deep sandstone aquifers. Radium is a natural element found in rocks and water in deep sandstone.

The United States Environmental Protection Agency (EPA) has established a limit of five picocuries of radium per liter of drinking water. The Wisconsin DNR adopted the EPA standard of five picocuries per liter; however, the DNR has not adopted the EPA's guidelines for testing water to determine compliance with the federal standard. This bill, LRB 3797/4, requires the DNR to allow Wisconsin communities to follow EPA-established testing guidelines in ensuring drinking water meets federal health standards. Simply put, this bill will allow testing to be done between the point that the water enters the public water distribution system

State Capitol • PO Box 7882 • Madison, WI 53707-7882 • 1-800-334-1442 • 608-266-5400 • 608-267-6790 fax
Email: sen.lazich@legis.state.wi.us Web: http://www.legis.state.wi.us/senate/sen28/news/

and the first customer. This is consistent with EPA guidelines. You will hear a technical explanation of the federal testing guidelines from an engineer who has worked for many years on issues relating to water quality.

Essentially, LRB 3797/4 allows blending of water with differing levels of radium within the water distribution system, provided the amount of radium in the water is at or below the federal safe drinking water standard before the point of consumption. Rather than testing at the wellhead to determine whether water meets the radium standard, as the DNR requires, testing may be done between the point of entry into the distribution system and before the first customer consumes the water.

The DNR may appear today and testify against the bill on the grounds that this testing procedure allows certain individuals to receive larger doses of radium than other individuals hooked up to the same system. Some refer to these larger doses as blasts of radium. Under this bill, <u>all</u> individuals will receive drinking water that <u>meets</u> federal health standards. To remain in compliance with the federal standard, a community must sample quarterly and the average must be at or below five picocuries per liter for the entire system. The DNR is currently allowing the communities of Waukesha and Green Bay to do this in-system blending under their consent orders. I am curious to know why it is acceptable for the residents of those communities to drink blended water, with possible exposure to these bursts, and it is not acceptable for other communities.

This bill will give communities another option to ensure their residents' drinking water meets federal health standards for radium. The bill is a reasonable response to requests from local officials that they be allowed to meet the federal safe drinking water standards in a manner acceptable to the EPA and in accordance with the EPA's testing guidelines. Without this legislation, the DNR will force Wisconsin communities to spend millions of dollars to meet the federal standard for radium at the well head while the federal government requires that the standard be met before consumption.

Governor Doyle recently signed Act 118, the Job Creation Act, which focused on regulatory reform. It was recognized that overly burdensome, unnecessary state regulations were harming the state's economic viability. As legislators, we have all heard from local officials that costly state mandates make it difficult for them to balance their budgets. Here, the DNR's insistence that water be tested at the entry point rather than prior to consumption is impractical and unnecessary. LRB 3797/4 will give local governments another way to provide safe drinking water to their residents. I respectfully ask that you support this bill.

Waukesha Water Utility

Memo

Support

DATE: February 19, 2004

TO: Members of the Senate Committee on Environment and Natural Resources

FROM: Daniel S. Duchniak, P.E., General Manager

RE: **LRB 3797/4,** By Senator Lazich; Representative Gundrum: Relating to connection of water sources producing water that contains radium 226, radium 228, or gross alpha particle radioactivity to public water systems

I am writing you today to urge your passage of bill LRB 3797/4, relating to public water systems and the point of sampling for a representative system sample.

This bill provides that DNR may not prohibit the connection of a water source that produces water with a concentration of radionuclides that exceeds a maximum contaminant level to a public water system if the maximum contaminant level is not exceeded at the point in the water distribution system at which water is sampled. The bill also requires DNR to allow the sampling to be conducted in the water distribution system at a point between the entry point of water from the water source and the service connection that is closest to that entry point if the samples taken are representative of the water normally provided to that service connection.

It is important to note that the result of this bill would not compromise the health and welfare of the general public in any manner. The resulting water provided to the customer would be in compliance with the MCL established by the EPA for radionuclides.

This bill would assist the Waukesha Water Utility in its ability to blend drinking water within the distribution system, once the system is modified to allow for this, potentially saving the Utility and its customers of the construction of new infrastructure necessary to blend the water.

As you can see, this affords the Waukesha Water Utility another option when dealing with compliance with the radionuclide standard; an option that could result in substantial savings to our customers.

Thank you very much for your time. If you have any questions or need any further information, please do not hesitate to contact me.

Ruekert·Mielke
engineering solutions for a working world

MEMO

TO: Senate Environment and Natural Resources Committee
FROM: Steven H. Schultz, P.E.
DATE: February 19, 2004
RE: LRB-3797/4

I work for Ruekert & Mielke, inc. a Waukesha based engineering consultant. As part of my duties as Water Supply Department head I get involved with many local water utilities. In the Waukesha area, Radionuclides in drinking water is a major issue. Today, I come representing the City of New Berlin and the Village of Sussex on this issue. While I am not directly representing other communities I have worked on similar issues with the City and Village of Pewaukee, city of Brookfield, Village of Menomonee Falls, City of Beloit, City of Muskego, Village of Mukwonago, Village of Eagle and the City of Waukesha.

All these communities, and 53 or so statewide, are facing huge projects to deal with the issue of Radium and Gross alpha in drinking water. My firm is assisting communities in finding cost effective solutions to the problem. While we are not here to debate the merits of the standards for the substances in drinking water, it should be noted that many believe the standards are not based on good science and that there are not substantial risks associated with the consumption of water containing the levels we are discussing.

I assisted five communities in recently negotiating Consent Orders with the Wisconsin DNR. At the first of the meetings, I suggested to the DNR representatives that communities should be allowed to sample the water that the customers were receiving on a daily basis to see if the water was in line with the standards. This would mean sampling in the distribution system, near wells before any customers were connected. Sampling sites would be set up near each well or source of supply. I was repeatedly told that a code provision in NR 809.10 required that any source of supply that exceeded a standard could not be connected to the system. DNR indicated that this meant the wells would have to be disconnected or expensive treatment installed.

In order to keep costs down for communities in these tough budget times, this did not make sense to me. Upon investigating further, I was informed by EPA representatives that the EPA was interpreting their own rule as allowing this type of testing to determine compliance. In fact, the guidance written by EPA references this type of testing.

Basically, what this proposal will allow is systems to test the water the customers are receiving. In areas where wells are provided only to meet peak demands during hot, dry weather or meet emergencies such as fires, the current rules require these wells to be treated or replaced. Costs for the projects to do this have been estimated between $500,000 and $1,000,000 per well or more. This proposal will allow the wells which are

W233 N2080 Ridgeview Parkway • Waukesha, Wisconsin 53188-1020
(262) 542-5733 • Fax: (262) 542-5631 • www.ruekert-mielke.com

needed only a few times during the year, to remain in service as long as all EPA requirements are being met.

To meet the EPA requirements for providing safe drinking water, the proposal allows communities to sample in the distribution system. During normal times, wells that are in compliance with the EPA safe drinking water standards would be providing water to the system. The EPA rules allow samples to be taken four times during the year, one in each quarter. These samples can then be composited or averaged. This type of averaging is allowed because the health risks are based upon a lifetime exposure, not a one time exposure such as for other more potentially harmful substances. Because the EPA rule was written and interpreted this way, it allows the sample averaging. This proposal puts Wisconsin rules in line with EPA safe drinking water rules. It also has the potential of saving communities such as New Berlin and Sussex literally millions of dollars.

I have also been in attendance at the DNR Secretary's Innovative Stake holders Group meetings in a professional status. One of the initiatives of that group is to encourage business development in Wisconsin while improving the environment. Keeping water rates low will help attract business. The environment is helped by not having to concentrate radionuclides and then dispose of them in a hazardous landfill, discharge them to our streams and rivers, or dispose of them in other manners. This will also help worker safety. Any reduction in the handling and disposal of concentrated radionuclides should be viewed as environmentally beneficial and better for workers.

In my professional opinion, this proposal will provide safe drinking water as defined by EPA while allowing many communities to experience significant savings. Points to remember regarding LRB 3797/4 are:

- It provides Safe Drinking Water as defined by EPA
- It will potentially save Millions of dollars in treatment costs for up to 53 Utilities
- It protects the environment by not concentrating Radionuclides
- It protects the environment by not introducing more salts to the streams resulting from larger softeners
- It will help keep water rates low thereby reinforcing the business climate
- It is in line with EPA recommended practices as described in Guidance issued by EPA on this matter

Respectfully Submitted,

Steven H. Schultz

Steven H. Schultz, P.E.

SB551 Radium bill

Kedzie, Neal

From: Sen.Lazich
Sent: Monday, January 26, 2004 2:30 PM
To: *Legislative Everyone
Subject: REMINDER -- Co-Sponsorship of LRB 3797/2, relating to public water systems

Representative Gundrum and I are currently circulating LRB 3797/~~2~~ /4 for co-sponsorship. The bill will allow communities with wells that exceed the federal radium standard to keep the wells connected to the water distribution system. Consistent with federal law, communities may use water from these wells as long as the radium level of the water between the well and the first customer is below the standard of 5 picocuries per liter.

At a Friday morning meeting of local government officials, I was informed that this legislation will save one community $2 million and another community $25 million. Wisconsin municipalities affected by the radium issue include:

Allenton
Allouez
Ashwaubenon
Bellevue
Beloit
Brookfield
Brownsville
Dalton
De Pere
Delafield
✓Eagle
Edgerton
Fond du Lac
Germantown
Green Bay
Forest Junction
Gresham
Harbor Lights
Hartford
Holland
Howard
Hudson
Hustisford
Johnson Creek
Kaukauna
Lawrence
Ledgeview
Mukwonago
Muskego
New Berlin
North Fond du Lac
Oconto
Peshtigo
Pewaukee
Princeton
Sussex
Waukesha

If you would like to co-sponsor this legislation, please contact my office at 266-5400, Rep. Gundrum's office at 267-5158, or respond to this e-mail **not later than 4 p.m. on Thursday, January 29, 2004.**

- No state making any changes re. mixing
- (2) Wells being considered in Minnesota
- Proposed Averaging (Quarterly) over 1 yr. for sampling
- 3 yr ext. 2006 DNR negotiated w/ EPA

Consent orders written by consultant for several communities

Entry Pt. } interchangeable
Sampling Pt. }

Must disconnect a well that does not comply

w/ Risk assessment

DNR would allow @ 1st Service Pt. (Not an issue)

Draft Statutory Language (LRB 3797/2)

Based on the Legislative Reference Bureau analysis of LRB 3797/2, the Departments understanding of the proposed language is; (a) to allow public water systems to keep radium contaminated wells connected to their distribution systems indefinitely and, (b) allow public water systems to move the compliance point for radionuclide monitoring such that at the sampling point, mixing of water from the contaminated well and other sources might dilute the contaminant concentration and thus the water at the new sampling point would meet Maximum Contaminant Level (MCL) requirements for radium.

Issues:

1. Allows certain customers within the public water system to preferentially receive high doses of radium contaminated water.

2. Allows retention of contaminated wells indefinitely.

3. Poses a direct threat to major drinking water aquifers in the State.

4. Allows "mixing" within a distribution system.

5. Allows any well, public or private, with a radium violation to be connected to a municipal system, even if the well does not comply with other MCLs or construction and public safety requirements.

6. Nationwide, we are aware of only one state that is considering this for one specific water system (having only two wells).

7. Wisconsin is currently allowing flow weighted averaging to be used as an interim means to meet the December 8, 2006 deadline for compliance with the radium standard. This allowance has been offered in two specific locations. The first location is Brown County and the Central Brown County Water Authority and the second location is the City of Waukesha. The other systems with radium violations have all indicated in their consent agreements that they will achieve compliance at every entry point by December 2006.

8. The Wisconsin Department of Health and Family Services, Division of Health, agrees that application of drinking water standards at the entry to the distribution system is more protective of public health than regulating at some point in the distribution system.

Yr. 1978 (5) pico curie
Standard set

*26 yrs

2004

(4) Communities
need to make
radium adjustments

(5) over 15,000 pop.

Radium in Wisconsin drinking water: an analysis of osteosarcoma risk.

Archives of Environmental Health, July-August, 2002, by Clare E. Guse, Anne M. Marbella, Varghese George, Peter M. Layde

OSTEOSARCOMA is one of the 3 main subtypes of bone cancer. It arises most often from the growing ends of long bones. Data from the Surveillance, Epidemiology, and End-Results (SEER) program of the National Cancer Institute indicate that osteosarcoma has a bimodal age distribution. (1,2) The first peak appears between the ages of 5 yr and 20 yr for both males and females, and a second peak is seen among males over the age of 65 yr. Males have a higher incidence (per 100,000) than females among both whites and blacks (i.e., 0.35 in white males and 0.37 in black males; 0.25 in white females and 0.29 in black females). (2)

The results of epidemiological studies have shown an association between exposure to high doses of radium and bone cancers? The exposures occurred among patients treated with radium for other cancers, and among radium-dial painters who adjusted the point on their brush with their lips. (3,4)

There is concern about the risk of osteosarcoma from low levels of radium in drinking water. According to data from the Wisconsin Department of Natural Resources (DNR), the highest levels of radium in drinking water in the state are found in water drawn from 2 rock formations: (1) the deep sandstone of the state's eastern quarter, and (2) the crystalline granite rock of north central Wisconsin. (5) Elevated radium levels typically occur in public water supplies. Generally, private wells are not drilled into the deeper geologic formations that contain higher concentrations of radium.

In 3 North American studies investigators assessed osteosarcoma risk in humans in relation to radium in drinking water. The Midwest Environmental Health Study was an early study that examined osteosarcoma deaths in communities with different levels of radium-226 in drinking water. (6) In that study, elevated levels of radium-226 were defined as levels exceeding 3.0 picocuries per liter (pCi/l; 1 pCi/l = 0.037 Bq/l). A total of 111 communities in Illinois and Iowa were identified as having elevated radium levels in their drinking water during the study period 1950-1962. The researchers reported that, compared with the control group, the exposed population had higher osteosarcoma mortality rates in 6 of the 9 age groups, and significantly higher rates in the 20-29 yr and 60-69 yr age groups.

Two more-recent reports have described epidemiologic studies of the association of radium in drinking water and the occurrence of osteosarcoma. Moss et al. conducted a case-control study in Wisconsin and compared 167 individuals with osteosarcoma diagnosed between 1979 and 1989. (7) The control group contained 989 patients diagnosed with other cancers during the same period as for the cases. The investigators reported a weak association that was not statistically significant (odds ratio [OR] = 1.5; 95% confidence interval [Cl] = 0.8, 2.8) between osteosarcoma and water-borne radium exposure. In that study, water-borne radium exposure was defined as residence in a county with a water system containing gross et-radiation of 9 pCi/l or higher. All residences in other counties were coded as low-radium residences.

Finkelstein and Kreiger conducted a case-control study, similar to the study by Moss et al., (7) of bone cancer in youths living in Ontario, Canada, and they also used patients with other cancers as controls. (8) Those investigators reported an association between the risk of osteosarcoma and birthplace "exposures" to even relatively low levels of radium in drinking water, but at a p = .10 level (OR = 1.77; 90% Cl = 1.03, 3.00). No significant association was found between osteosarcoma and lifetime exposure to radium in drinking water (OR = 1.33; 90% CI = 0.76, 2.24).

We conducted a population-based case-control study in Wisconsin to examine the association between radium in drinking water and incidence of osteosarcoma.

Method

Study population

Cases. The case group comprised Wisconsin residents who had an initial diagnosis of osteosarcoma reported to the state Cancer Reporting System between 1980 and 1997.

Controls. For each case, we selected 10 controls from the general population of Wisconsin. The universe of potentially eligible controls was constructed from the 1980 and 1990 decennial federal census data on the basis of age, sex, and ZIP code of residence. For cases diagnosed between 1979 and 1984, we used the 1980 census data, and for the cases diagnosed between 1985 and 1997, we used the 1990 census data. The following method was used on each census. On the basis of age, sex, and number of persons residing in each ZIP code, as specified in each census, we generated a population database with 1 record per person in Wisconsin. Each population database had approximately 5 million records. Using Stata (9) statistical software, we extracted 10 random controls per case. This method guaranteed equal probability for every subject in the Wisconsin population.

ZIP codes refer to the place where mail is received, which, in most cases, is a residence. We were unable to use 1 case and 2 controls in our analyses because the subjects' ZIP codes did not match a ZIP code for which we had ecological (census-derived) data. One control's ZIP code was used for a Minnesota border community; the other control ZIP code and the case ZIP code were both post office box ZIP codes, which could not be clearly assigned to another ZIP code. The loss of these subjects resulted in a total of 319 cases and 3,198 controls.

Data sources

Radium data. The Wisconsin DNR requires periodic testing of public water supplies to screen for potentially elevated levels of radium. The level of gross [alpha]-radiation activity is used as a screening test for elevated radium levels. If the gross [alpha] level is less than 3 pCi/l, no testing for specific radium isotopes is required. If the gross [alpha] level is greater than or equal to 3.0, testing for radium isotopes (radium-226 and radium-228) is required, as is more frequent sampling.

A data set with Wisconsin public water utilities' gross [alpha], radium-226, and radium-228 levels from 13 September 1978 through 11 August 1999 was obtained from the Wisconsin DNR. The data set included sample location, ZIP code, sample date, analyte measured, measurement units, and level of analyte found. Subsequent use of the word "radium" in this article refers to the combined total of radium-226 and radium-228, unless otherwise noted. We used ZIP codes in this study to link radium level, residence of cases and controls, and ecological census data. To ensure that the correct radium level was assigned to each Wisconsin ZIP code, we conducted telephone surveys of the following public water utilities to obtain lists of the ZIP codes each utility serviced: (a) utilities servicing cities with populations greater than 50,000, (b) utilities with radium levels higher than 20 pCi/l, and (c) utilities located near ZIP codes that do not have their own utility service.

We used a federal government website--http://venus. census.gov/cdrom/lookup (19 January 2001)--to verify that selected ZIP code areas, that did not have public water utilities and were not serviced by nearby public utilities, were rural, and, therefore, most likely obtained their water from private wells. In these cases, negligible exposure to radium in drinking water was assumed. Investigative samples in areas of the water system not representative of water delivered to the public (e.g., backwash, test pumps) were excluded. Nonrepresentative samples were determined by a DNR official. Overall, 138 investigative samples from 35 water supplies were excluded.

Public water supplies can be classified as municipal or other than municipal. Other-than-municipal water supplies are those operated by apartment owners, condominium associations, subdivisions, neighborhood water trusts, mobile home parks, nursing homes, and health-care centers. Radium measurement records were coded as being from either municipal or other-than-municipal sources.

Cancer data. The Wisconsin Cancer Reporting System is a population-based registry that collects, manages, and analyzes cancer incidence and mortality data on Wisconsin residents. (10) Out-of-state cancer registries provide reports on Wisconsin residents diagnosed in their states to the Wisconsin registry under data exchange agreements with the Wisconsin Cancer Reporting System. Registry records are also matched annually to the Wisconsin resident death file so that cases not reported by the regular reporting process are identified. During the time period of our study, we estimated data completeness to range from 93% to 95%. (11,12) The Wisconsin Cancer Reporting System offers statewide training sessions to reporting facilities. The training focuses on increasing complete case finding, timely reporting, and compliance with the cancer reporting statute and administrative rule.

For each osteosarcoma case reported, the Wisconsin Cancer Reporting System provided the year of diagnosis, age at diagnosis, sex, race, ZIP code of residence, and county of residence at diagnosis.

Census data. Census data from 1980 were obtained from the University of Wisconsin's Applied Population Laboratory in Madison, Wisconsin. Census data from 1990 were abstracted from the CensusCD[TM] from GeoLytics, Inc. (New Brunswick, New Jersey). Data used in this study included 1990 Wisconsin ZIP code population totals, by sex and detailed age groups, as well as the following ecological data by ZIP code: percentage of various races (white, black, Asian/Pacific Islander, Native American, and other); income (median household income and percentage below poverty level); and percentage in various occupations (administrative support, farming, handlers/equipment cleaners/laborers, machine operators, precision production, service in a private household, professional, protective services, sales, technicians, transportation, and administrative/ executive/managerial). (13)

We calculated population density by dividing the 1990 ZIP code population by the area in square miles (on the basis of data provided with the ArcView 3.1 Geographical Information System (GIS) mapping software (14)).

Statistical method. Although our preliminary analysis did not suggest a strong trend in the highest radium level over time within ZIP code areas, we assigned an index year to each control that was equal to the year of diagnosis for the corresponding case. Exposure to radium in drinking water was assessed by the reported levels in the ZIP code prior to the year of diagnosis for cases, and prior to the index year for controls.

For some analyses, missing total radium levels were replaced with an estimate that was based on the gross [alpha] level, given that radium goes through [alpha] decay. A plot of total radium and [alpha] values showed a generally linear relationship. Although a Box-Cox transform (15) to normality suggested a square-root transformation of total radium, an analysis with the square root did not yield a substantially better fit for the data ([R.sup.2] = .56 vs. [R.sup.2] = .62). Inasmuch as our goal at this point was to only estimate the missing values, the linearity assumption was crucial but the normality assumption was not. Therefore, we used standard linear regression to estimate total radium values from [alpha] values. The regression equation used was based on all records that gave both total radium and gross [alpha] levels, and was as follows: total radium = 1.447963 + (0.3212015*gross [alpha]). For 1,682 (48%) subjects (i.e., 156 cases and 1,526 controls), no radium values were available without imputation or assignment. In addition, when imputation was used, most cases and controls had 1 or more imputed values that contributed to their selected radium value.

Most of the subjects with no radium values available resided in ZIP codes with water supplies that had median gross [alpha] levels less than 3 pCi/l, for which no testing for specific radium isotopes was required. In these ZIP code areas resided 134 cases (42%) and 1,351 controls (42%). Thirteen cases (4%) and 99 controls (3%) were located in ZIP code areas that had no public water supplies, and we presumed that they had negligible exposures to radium. Only 9 cases (3%) and 76 controls (2%) resided in ZIP code areas characterized by water supplies that had median gross [alpha] levels of 3.0 pCi/l or higher. These ZIP code areas should have had radium isotope measurements conducted, but this did not occur.

For some ZIP codes, we had radium/[alpha], levels measured only after the diagnosis/index year occurred. We used these levels if the water supply for that ZIP code had been in operation for at least 1 yr prior to the diagnosis/index year. These "delayed" data were used for 17 cases (5%) and 82 controls (3%) and involved 66 water supplies. Sixteen of the 17 cases either had median [alpha] levels below 3 pCi/l or had radium levels. One case had a high median [alpha] level, but there was no radium level. All of the 82 controls either had median [alpha] levels below 3 pCi/l or had radium levels.

Analytic approach. Confounder-adjusted ORs for osteosarcoma and different measures of radium in the drinking water were calculated with logistic-regression analysis. (16,17,18) Case-control status was the outcome variable. (19) In this analysis, our purpose was to quantify the association of radium level in drinking water with the risk of osteosarcoma--adjusting for confounding factors and considering important effect modification, or interaction, of independent variables. (20,21) Therefore, the analysis was based on the "change in effect" model-building strategy appropriate for analyses focusing on estimating the unconfounded association of a single risk factor with the outcome variable. (22) One of the radium exposure indices (the main risk factor) was included in all models. Other variables were included in the model only if they altered the log OR for the association of radium and osteosarcoma by at least 15%. (20,21) Inasmuch as bimodal distribution of osteosarcoma cases may indicate a different etiology in younger cases than in older cases, we also conducted a stratified analysis and separated those subjects into 4 age groups: (1) < 10 yr, (2) 10-20 yr, (3) 21-64 yr, and (4) [greater than or equal to] 65 yr.

Two parameterizations of radium level in drinking water were used for both the median and maximum measures of radium exposure: (1) an ordinal variable categorized into 3 levels of total radium concentration (< 2.5 or gross [alpha] < 3 pCi/l in the absence of a radium measurement, 2.5-4.9 pCi/l, and [greater than or equal to] 5 pCi/l), and (2) the radium level as a continuous variable with missing radium levels imputed from gross [alpha] levels using the aforementioned equation. In addition, two 5-category radium measures were examined for the median and maximum radium, with the additional 2 categories based on the 95th and 99th percentiles of the respective distributions.

Variables considered as candidates in the models included age, sex, and the following ZIP code characteristics: population density; median household income; and percentages for male, white, black, Asian/Pacific Islander, Native American, or "other" race; 5-20 yr of age or [greater than or equal to] 65 yr of age; below the poverty level; and various occupations (administrative support, farming, handlers/equipment cleaners/laborers, machine operators, precision production, service in a private household, professional, protective services, sales, technician, transportation, administrative/executive/managerial). (12)

The relationship between radium exposure and osteosarcoma within age groups and between sexes was explored. The interaction of sex and population density was also examined as a possible confounder, on the basis of results of another study. (7)

Model assumptions. Models 1 and 2 (Table 1) used radium measured as a continuous variable, with imputation for missing radium values (as given by the aforementioned equation). Separate analyses were performed for median and maximum radium levels.

The maximum and median ordinal measures (Models 3 and 4) did not involve imputation of missing radium values with gross [alpha] values. When total radium and gross [alpha] were missing, the associated case/control was assigned to the lowest radium category on the assumption that these are likely to be areas where private wells were in use. If radium values were missing and the gross [alpha] level was greater than or equal to 3, then the observation was excluded from the analysis, regardless of case or control status.

Additional radium measures used were variations on these 4 combinations of maximum/median and continuous/ordinal, as follows: (1) median, continuous radium model after excluding other-than-municipal water supplies (Model 5); (2) median, continuous radium model after excluding missing radium values (Model 6); (3) median, ordinal radium model with imputation for missing radium values (Model 7); (4) maximum, ordinal radium model with the highest category further divided into 3 subcategories based on the 95th and 99th percentiles of the maximum radium distribution; and (5) median, ordinal radium model with the highest category further divided into 3 subcategories based on the 95th and 99th percentiles of the median radium distribution.

We used Wilcoxon's rank-sum test to compare the ecological characteristics of the cases and controls. The Stata 6.0 (9) and SAS 6.12 (23) statistical software programs were used for statistical analyses, and the ArcView 3.1 GIS (14) mapping software was used for all mapping of radium levels and osteosarcoma cases.

Results

Between 1980 and 1997, 320 Wisconsin residents who had an initial diagnosis of osteosarcoma were reported to the state cancer-reporting system. This value is equivalent to an incidence of 3.63 new cases per million person-years on the basis of the 1990 Wisconsin population, which is comparable to published data and implies similar ascertainment. Limited information has been published on osteosarcoma incidence rates. It is most often combined with other bone and joint cancers when reported. A study in New York state reported rates of 2.1-4.6 new cases per million per year in various age-sex categories for the years 1976-1987. (24) Another study in 5 San Francisco Bay Area counties reported a rate of 2.1 new cases per million per year for 1973-1986 in persons 30 yr of age and younger. (25) A 1991 report, based on the National Cancer Institute's SEER data, reported rates of 3.49 and 2.89 per million for males and females, respectively, aged 0-24 yr during the period from 1973 to 1986, (26) and a SEER monograph on childhood cancer reported a rate of 4.8 per million per year for those under age 20. (27) Cases and controls. Selected characteristics of subjects and subjects' ZIP code of residence are reported in Table 2. Subject-specific age and sex information was provided for cases and obtainable for the census-derived control samples. Several "ecological" characteristics of cases and controls were determined from census data on the basis of their ZIP code of residence. Characteristics considered as possible confounders or effect modifiers were (a) percentage engaged in the various occupations, (b) percentage black, (c) population density, (d) percentage below the poverty level, and (e) median household income. Mean population density and median household income (not shown in Table 2) were not significantly different for cases and controls. The percentage for only 1 occupational category--handlers/equipment cleaners/laborers--was significantly different between cases and controls (Wilcoxon rank-sum test, p = .02).

Regarding the distribution of cases and controls within ZIP code areas, cases were spread across the state, with higher numbers generally found in areas with higher population density. Controls represented the majority of Wisconsin ZIP codes and, again, were more frequent in population centers. Figure 1 shows the osteosarcoma rate per million person-years, by ZIP code.

Radium levels. Figure 2 shows the distributions of the continuous radium measures associated with cases and controls. Medians, interquartile ranges (25th to 75th percentile), and means were similar for the 3 different median measures, although exclusion of other-than-municipal water supplies increased the number of cases and controls assigned a median radium level of zero. Use of maximum values resulted in distinctly increased associated levels. Ranges for the measures were 0-21.1 pCi/l for all 3 median measures and 0-90.6 pCi/l for the maximum measure.

[FIGURE 2 OMITTED]

Table 3 shows the distribution of radium levels within 3 categories: (1) radium < 2.5 or radium missing and gross [alpha] < 3, (2) radium 2.5-4.9, and (3) radium [greater than or equal to] 5. The differences in the 3 measures occurred primarily in the percentage in the lowest and highest categories. As expected, use of the maximum radium level resulted in a higher percentage in the top category.

Median and maximum radium values by ZIP code are shown in Figures 3 and 4, respectively. These 2 figures include radium values obtained by imputation with gross [alpha] levels, leading to a small proportion of missing data for all the ZIP codes. The radium values in these figures are those used in Models 1 and 2.

[FIGURES 3-4 OMITTED]

Association of radium level and osteosarcoma. We considered 9 different models in the examination of the association between radium in drinking water and osteosarcoma. In each model, case/control status was used as the outcome variable; however, the models varied in the structure of the radium variable and the types of substitution used for missing radium values. The independent variables in the final Model 1 are shown in Table 4. The median radium level in an individual's water supply prior to diagnosis was not significantly associated with osteosarcoma. Only age groups younger than 10 yr or 65 yr and older, and the percentage in the handlers/ equipment cleaners/laborers occupation group, were significantly associated with osteosarcoma and showed increased odds of osteosarcoma. The results for the other models were similar. In no instance was the relationship between radium exposure and osteosarcoma significant (Table 5).

To examine risk at the highest levels of radium exposure, we divided the top ordinal maximum and median radium categories into 3 subcategories on the basis of the 95th and 99th percentiles of the respective distributions. The results are shown in Tables 6 and 7, respectively. Again, we did not see significant associations in these high-exposure categories.

Association of radium and osteosarcoma in age categories. Using Models 1 and 2, we calculated the ORs within age groups for the relationship between the continuous median and maximum radium measures and osteosarcoma. No significant association was found in any age group.

Discussion

In this study, we found no association between radium in Wisconsin drinking water and osteosarcoma. The lack of association was seen with all the different radium measures used (median ordinal and continuous, maximum ordinal and continuous), and with the different sets of radium data (with and without imputation, excluding other-than-municipal water supplies, and excluding missing radium values). Because the different radium measures entail different assumptions, the consistency of the results is reassuring. Continuous measures provide more statistical power, although, as used here, they also imply a monotonic relationship. Ordinal measures are more useful for detecting a threshold effect. The use of imputation for missing radium levels allowed us to include those water supplies with low gross [alpha] values. Likewise, the use of radium or gross [alpha] data occurring after the index year (delayed data) prevented the exclusion of those cases and controls who had no radium data prior to the index date. An analysis that excluded other-than-municipal water supplies was done because those sources typically serve a small portion of a ZIP code area. We also excluded cases and controls who resided in ZIP code areas for which radium data were missing for 1 analysis, to ensure that the results were not being skewed by the assumption of zero radium levels in those instances.

The expected bimodal relationship between age and osteosarcoma (1,2) was seen in all models. The weak but significant association between percentage of handlers/equipment cleaners/laborers in the ZIP code of residence and the risk of osteosarcoma was not expected. We included that variable, as well as percentage below the poverty level, to control for any confounding influence, and to provide the best estimate of the association between radium and osteosarcoma.

Limitations. A major limitation of this study is the fact that it is an "ecological" study, that is, detailed information on potential risk factors for osteosarcoma was not available from individuals with and

without osteosarcoma. Rather, the characteristics of their ZIP codes of residence were used. Given the method of constructing the control populations from the 1980 and 1990 federal censuses, we cannot be certain that a control was alive at the time of diagnosis of the corresponding case.

Some ZIP code areas were served by more than 1 water supply and, especially in the instance of other-than-municipal water supplies, a given water supply may have served only a small portion of a particular ZIP code area. We addressed this limitation by doing analyses with and without the other-than-municipal water supplies. We found no difference between these 2 analyses. Imputation of missing radium values from gross [alpha] values entails some uncertainty and may introduce misclassification; however, imputation may be preferable to excluding these cases. In any case, we analyzed the data both ways and saw no appreciable difference.

In addition, we do not know how long a specific individual with cancer had resided in (and consumed the water of) the ZIP code of their residence at the time of diagnosis. However, this limitation in gathering potential exposure history is not specific to this study design, but is a result of a high fatality rate for osteosarcoma. Many of the patients diagnosed in the past are no longer alive to provide more detailed residential histories. The mobility of subjects may introduce misclassification of those subjects into radium exposure groups. We would expect this misclassification to be random and to have the effect of attenuating the association between osteosarcoma and radium exposure toward the null. (28) We would also expect that misclassification would occur more often for adult subjects, given the same rate of relocation per year for children and adults. However, no differential effect was seen among age groups.

Given that the amount of radium consumed by subjects, and the timing, are unknown, we cannot address the issue of latency. Also, this study addressed only osteosarcoma risk; no inferences can be made about other types of cancer.

Despite these limitations, our methods had several advantages over those of previous studies that examined the association between radium in drinking water and cancer risk. In contrast to studies by Petersen et al. (6) and Moss et al., (7) we used the total of radium-226 and radium-228--not just the 226 isotope or a gross [alpha] proxy--whenever any radium measurement was available. Our use of ZIP-code-level radium data, rather than county or community data, (6,7) should have provided a more accurate measurement of exposure. In addition, we used controls from the general population, rather than controls with other cancers, (7,8) and we looked at various indices of radium exposure, rather than a single measure.

An ideal study of the association of radium in drinking water and osteosarcoma risk would be conducted in areas with a large sample of cases, and would (a) include interviews of cases and controls to obtain lifetime residential histories, (b) collect water samples from locations where subjects had lived (to improve exposure measurement), and (c) collect individual-level data on demographics and other potential confounders to increase the accuracy of covariate estimation. Although such a study would be both expensive and time-consuming, it would provide valuable information on other risk factors for osteosarcoma and clarify the health effects of radium in drinking water. It is our hope that the results of our study will provide further motivation for conducting such a definitive, prospective study.

Table 1.--Summary of Logistic Regression Model Assignments and Assumptions

	Radium measure	
Model	Continuous/ ordinal *	Median/ maximum ([dagger])
1	Continuous	Median
2	Continuous	Maximum
3	Ordinal	Maximum
4	Ordinal	Median
5	Continuous	Median
6	Continuous	Median
7	Ordinal	Median

	Missing values	
Model	Radium only ([double dagger])	Radium and gross [alpha] ([section])
1	Imputation with [alpha]	Assign 0
2	Imputation with [alpha]	Assign 0
3	Max [alpha] < 3--lowest category Max [alpha] [greater than or equal to] 3--exclude	Assign to lowest radium category
4	Median [alpha] < 3--lowest category Median [alpha] [greater than or equal to] 3--exclude	Assign to lowest radium category
5	Imputation with [alpha]	Assign 0
6	Imputation with [alpha]	Exclude
7	Imputation with [alpha]	Assign 0

	Use of:	
Model	Delayed data (#)	Other-than-municipal data
1	Yes	Yes
2	Yes	Yes
3	Yes	Yes
4	Yes	Yes
5	Yes	No
6	No	Yes
7	Yes	Yes

Notes: pCi/l = picocuries per liter, Bq/l = becquerel per liter, [alpha] = gross alpha, and max = maximum.

* Radium as a continuous variable or as a 3-category ordinal variable (< 2.5 or gross [alpha] < 3 pCi/l, 2.5-4.9 pCi/l, 5 or more pCi/l; 1 pCi/l = 0.037 Bq/l).

([dagger]) Median or maximum radium value.

([double dagger]) Total radium (radium-226 plus radium-228) is missing, but gross [alpha] is not.

([section]) Rural ZIP codes where both total radium and gross [alpha] were missing were assumed to be in an area with private wells with negligible radium exposure (see Method section).

(#) Radium or gross [alpha] data occurring after the year of diagnosis or index year, but from a water supply in existence at least 1 yr prior to year of diagnosis or index year.

Table 2.--Characteristics of Cases and Controls

Variable	[bar]x Cases % (n = 319)	Controls % (n = 3,198)
Individual characteristics *		
Male	50.0	50.0
Age (yr) ([dagger])		
< 10	7.0	15.0
10-20	36.0	16.0
21-64	31.0	56.0
[greater than or equal to] 65	25.0	14.0
Characteristics of ZIP code of residences ([double dagger]) ([section])		
White	93.0	92.0
Black	5.0	5.0
Asian/Pacific Islander	1.0	1.0
Native American	0.7	0.8
Other race	0.6	0.9
Below poverty level	10.0	11.0
Occupation		
Administrative support	13.0	13.0
Farming	4.0	4.0
Handlers/equipment cleaners/laborers (#)	4.0	4.0
Machine operators	9.0	9.0
Precision production	10.0	10.0
Service in private household	0.2	0.2
Professional	11.0	11.0
Protective service	1.0	1.0
Sales	9.0	9.0
Technicians	3.0	3.0
Transportation	4.0	4.0
Administrative/executive/ managerial	8.0	4.0

Notes: [bar]x = mean. Occupational percentages were based on total population of ZIP code area. Unemployed persons and homemakers were not represented in the numerators.

(*) Sex and age were compared with [chi square] tests.

([dagger]) p < .001.

([double dagger]) These variables were based on 1990 census data.

([section]) Mean percentages were compared with Wilcoxon's rank-sum test.

(#) p < .05.

Table 3.--Distribution of Categorical Radium Measures in Drinking Water in Case and Control ZIP Codes in Wisconsin from 1978 to 1999

Category of radium level (pCi/l) *	Median ([dagger]) (%)	Median with imputation ([dagger]) (%)	Maximum ([dagger]) (%)
< 2.5 or gross [alpha] < 3	75.8	80.0	70.2
2.5-4.9	8.0	8.3	8.1
[greater than or equal to] 5	16.2	11.7	21.7

Notes: pCi/l = picocuries per liter; Bq/l = becquerel per liter.

* 1 pCi/l = 0.037 Bq/l.

([dagger]) N = 3,432 (88 missing), 3,517 (3 missing), 3,226 (294 missing), respectively; Models 4, 7, and 3 assumptions (see Table 1)

Table 4.--Logistic Regression Analysis of Osteosarcoma Risk and Median Total Radium Levels in Drinking Water in Wisconsin from 1980 to 1997, Using Model 1 *

Variable	Coefficient	SE	p	OR	95% CI
Median radium	-0.0168773	0.0287112	.5570	0.98	0.93, 1.04
Age (yr)					
< 10	-0.1712734	0.2372639	.4700	0.84	0.53, 1.34
10-20	1.4173550	0.1462033	< .0005	4.13	3.10, 5.50
21-64	Referent	--	--	1.00	--
65+	1.2013660	0.1590974	< .0005	3.32	2.43, 4.54
% handlers	0.1190670	0.0423944	.0050	1.13	1.04, 1.22
% below poverty level	-0.0137009	0.0076145	.0720	0.99	0.97, 1.00
Constant	-3.1759070	0.2132921	< .0005	--	--

Notes: SE= standard error, OR = odds ratio, CI = confidence interval, pCi/l = picocuries per liter, Bq/l = becquerel per liter; ORs represent the risk due to each variable, taking into account the influence of other variables in the model.

* N = 3,517. The radium measure used here was the median total radium (in pCi/l; 1 pCi/l = 0.037 Bq/l) prior to the year of diagnosis/index year, with imputation using median gross [alpha] for missing radium values.

Table 5.--Summary of Model Results with Regard to Radium and Osteosarcoma Association

	Type of radium measure	
	Continuous/	Median/

Model	Exclusions	ordinal *	maximum ([dagger])
1	None	Continuous	Median
2	None	Continuous	Maximum
3	Gross [alpha] [greater than or equal to] 3 and missing radium	Ordinal	Maximum
4	Gross [alpha] [greater than or equal to] 3 and missing radium	Ordinal	Median
5	Other-than-municipal	Continuous	Median
6	Missing radium	Continuous	Median
7	None	Ordinal	Median

		Radium association		
Model	Exclusions	Coefficient	p	95% CI
1	None	-0.0169	.557	0.93, 1.04
2	None	-0.0107	.196	0.97, 1.01
3	Gross [alpha] [greater than or equal to] 3 and missing radium	-0.3657 ([double dagger])	.158	0.42, 1.15
		-0.2024 ([double dagger])	.216	0.59, 1.13
4	Gross [alpha] [greater than or equal to] 3 and missing radium	-0.8814 ([double dagger])	.701	0.58, 1.44
		-0.2203 ([double dagger])	.223	0.56, 1.14
5	Other-than-municipal	-0.0155	.572	0.93, 1.04
6	Missing radium	-0.0121	.682	0.93, 1.05
7	None	0.2208 ([double dagger])	.275	0.84, 1.85
		-0.2431 ([double dagger])	.246	0.52, 1.18

Notes: CI = confidence interval, pCi/l = picocuries per liter, Bq/l = becquerel per liter, 1 pCi/l = 0.037 Bq/l.

* Radium as a continuous variable or as a 3-category ordinal variable (< 2.5 pCi/l or gross [alpha] < 3 pCi/l; 2.5-4.9 pCi/l, [greater than or equal to] 5 pCi/l).

([dagger]) Median or maximum radium value.

([double dagger]) Coefficients are shown for 2.5-4.9 pCi/l and [greater than or equal to] 5 pCi/l categories, respectively; lowest category (< 2.5 pCi/l or gross [alpha] < 3) is the referent.

Table 6.--Logistic Regression Analysis of Osteosarcoma Risk and Maximum Total Radium Level in Drinking Water in Wisconsin from 1980 to 1997 *

Radium level (pCi/l)	OR	95% CI
< 2.5 or gross [alpha] < 3	1.00	Referent
2.5-4.9	0.69	0.42, 1.15
5-20.6	0.81	0.56, 1.15
20.7-29.2	1.12	0.56, 2.23
[greater than or equal to] 29.3	0.49	0.15, 1.59

Notes: pCi/l = picocuries per liter; Bq/l = becquerel per liter, 1 pCi/l = 0:037 Bq/l, CI = confidence interval, and OR = odds ratio.

* N = 3,226. Model and assumptions are the same as in Model 3, except that the radium categories have been expanded as shown above. The additional 2 top categories were based on the 95th and 99th percentiles of the maximum radium distribution (i.e., 20.7 is the 95th percentile and 29.3 is the 99th percentile).

Table 7.--Logistic Regression Analysis of Osteosarcoma Risk and Median Total Radium Level in Drinking Water in Wisconsin from 1980 to 1997 *

Radium level (pCi/l)	OR	95% CI
< 2.5 or gross [alpha] < 3	1.00	Referent
2.5-4.9	0.92	0.58, 1.43
5-7.6	0.86	0.56, 1.33
7.7-8.95	0.49	0.21, 1.15
[greater than or equal to] 8.96	1.00	0.49, 2.05

Notes: pCi/l = picocuries per liter; Bq/l = becquerel per liter, 1 pCi/l = 0.037 Bq/l, CI = confidence interval, and OR = odds ratio.

* N = 3,432. Model and assumptions are the same as in Model 4, except that the radium categories have been expanded as shown above. The additional 2 top categories were based on the 95th and 99th percentiles of the median radium distribution (i.e., 7.7 is the 95th percentile and 8.96 is the 99th percentile).

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Requests for reprints should he sent to Clare E. Guse, MS, Department of Family and Community Medicine, 8701 Watertown Plank Road, Medical College of Wisconsin, Milwaukee, WI 53226.

E-mail: cguse@mcw.edu

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CLARE E. GUSE
ANNE M. MARBELLA
Department of Family and Community Medicine
Medical College of Wisconsin
Milwaukee, Wisconsin
VARGHESE GEORGE
Department of Biostatistics
University of Alabama at Birmingham
Birmingham, Alabama
PETER M. LAYDE
Department of Family and Community Medicine
Medical College of Wisconsin
Milwaukee, Wisconsin